Measurements of Tire and Roadway Dust Particulates in Chelyabinsk

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Abstract: - Harmful emissions from tire wear and roadway wear are released into the air during the operation of vehicles. Particulate road dust contains carcinogenic substances. The amount and dispersion of particulate matter in road dust was determined with a portable laser particle counter. On asphalt roads, 75% of the harmful emissions were 0.3 µm particulate matter. On dirt roads, 95% of emissions were from particles less than 1 µm. The amount of large fractions of harmful emissions did not exceed 1.5%, regardless of traffic intensity. 30 m from the roadway, the concentration of harmful substances reduced by five- to sevenfold. By 2030, the number of vehicles in Chelyabinsk will increase by 25%. This will increase the amount of harmful emissions from tire and roadway wear by 20 tons per year.

Key-Words: - Sweep from roadway; Non-exhaust gases; Road dust; Ecological safety of transport; Traffic intensity; Soil and asphalt roads.

Received: August 21, 2021. Revised: April 19, 2022. Accepted: May 20, 2022. Published: June 25, 2022.

1 Introduction

According to the World Health Organization, nearly 91% of the world's population suffers from poor air quality [1]. One of the reasons for this is the harmful effects of vehicles. The environmental impact of exhaust gases has traditionally been taken into account when assessing the impact of road transport [2-4]. European environmental standards regulate the content of harmful substances in the exhaust gases of road transport [5-7]. This has led to a decrease in the emissions of exhaust gases. However, together with the exhaust gases, solid particles of non-exhaust origin are emitted into the environment during the operation of vehicles. They are the result of wear on vehicle tires and road surfaces. These emissions have not yet been standardized by the laws of the world communities or United Nations rules [8-10]. The aim of the study is to assess the harmful emissions from the wear of tires and the roadway in Chelyabinsk.

Chelyabinsk, with more than a million inhabitants, is one of the most polluted cities in Russia. Many industrial plants in Chelyabinsk closed due to the economic situation between 1990 and 2021. However, the health of the population of Chelyabinsk continues to deteriorate, despite the decline in industrial production [11]. According to medical statistics, in 2017, 16,543 cases of cancer were detected in the Chelyabinsk region, which is 473 cases per 100,000 people. In 2019, cancer was diagnosed in 17,886 people, which is 514.6 cases per 100,000 people. The annual growth of oncological diseases was 2.5% [12]. There was also an increase in the incidence of cancer in children under 14 years of age. Lung cancer is leading type of cancer. Chelyabinsk Region ranks sixth among Russian regions and second in the Ural Federal District in terms of cancer rates [13-14].

The mileage of modern tires is 70–100,000 km. The tread height of modern tires is 7–9 mm which is completely worn down during operation [15]. According to the UK Environmental Protection Agency, end-of-life vehicle tire weights have been reduced by 10%. The amount of material used for tire wear varies from 1.5 kg for passenger car tires to 10 kg for truck tires (Table 1).

Table 1. Weight of the worn-out part of a car tire depending on the category of vehicles

Vehicle category	Tire tread wear (mm)	Maximum mileage (km)	Tire wear rate (g/km)	Mass of the worn part of the tire tread (kg)
Car	1.6	50,000–60,000	0.13	1.1–1.9
Truck	2	75,000	0.32	3.2–4.0
Bus	2	80,000–85,000	1.5	8.1–17.7

Considering that four wheels are installed on a passenger car, about 6 kg of tire dust in the form of a fine aerosol is released per car. During the operation of trucks, an average of 3 kg to 18 kg of tire dust is released into the environment during the entire service life of the tires [16].

More than 60% of solid particles in roadside dust contain carcinogenic substances [17-18]. Dust particles less than 10 microns in size are the most dangerous as such fine dust accumulates in the human body. Small fractions enter the respiratory tract, accumulate in the lymph nodes, and can lead to lung cancer [19-20]. Fine dust due to wear on vehicle tires and the roadway negatively affects human health. More than 50% of such dust can enter human lungs and cause allergies and cancer [21-22].

Studies by allergists and oncologists have revealed an increased sensitivity to cancer and allergic diseases in urban residents of houses located near highways [23]. The incidence of malignant neoplasms in the city is higher than in the countryside [24-25]. Frequent braking of vehicles in heavy urban traffic leads to intense abrasion of the roadway and vehicle tires. Tire wear during acceleration, braking and cornering is 1.5 times higher than in other driving modes. Therefore, the problem of harmful emissions of non-exhaust origin is urgent for large cities [26-28].

To assess the harmful effects of non-exhaust emissions, data on the dispersed and chemical composition of particulate matter from tire and roadway wear are needed. An experiment was carried out to obtain these data for Chelyabinsk.

2 Methods and Materials

The research was carried out by conducting our own experiments and data processing of the Chelyabinsk State Traffic Safety Inspectorate (STSI). The experiment consisted of several stages.

The first stage was measuring the amount and size of particulate matter in the emissions of non-exhaust origin. The measurements were carried out in dry, cloudless weather at an ambient temperature of +24 °C. Two types of roads in Chelyabinsk were selected for the study:

- Lenin Avenue, an asphalt road with high traffic intensity;
- Lermontova Street, a dirt road with low traffic intensity.

The amount and dispersion of emissions of solid particles into the air-dust mixture was determined by a hand-held laser particle counter Lighthouse Handheld 3016 (Fig. 1). The counter indicated the number of particles in the air sample and had six size ranges. Samples were taken 150 mm above the roadway. The counter recorded the duration of air sampling and the number of measurements at each sampling point.

Fig. 1. Laser particle counter Lighthouse Handheld 3016

The counter was battery operated and had a 9.25 cm touchscreen. The obtained data was downloaded to a computer using the LMS Express Data Transfer Software.

At the second stage of the experiment, a chemical analysis of the composition of emissions of non-exhaust origin was carried out. The metal content was measured by atomic adsorption. The results were processed using Microsoft Office Excel.

At the third stage of experimental studies, air samples were measured at a distance of 1 m, 30 m and 150 m from the roadways. Sampling for was carried out in accordance with the current regulatory documentation [29]. The assessment of the chemical composition at this stage was limited to heavy metals of the first hazard class.

Finally, based on STSI data on the forecast increase of the vehicle fleet in Chelyabinsk, a forecast was made of an increase in the amount of harmful emissions of non-exhaust origin.

3 Results

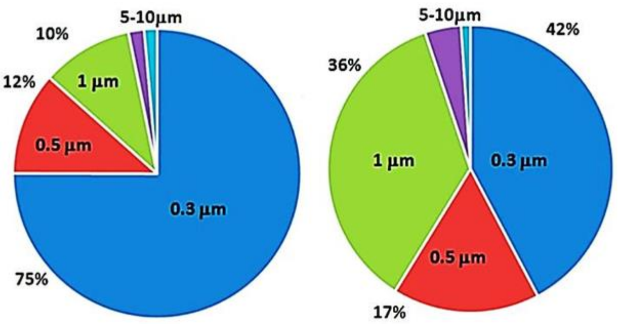
Air sampling (the first stage of the experiment) over the roadways was carried out for 2 seconds. The size of solid particles in the sample varied from 0.3 μm to 10 μm [30-31]. The amount and size of particulate matter above the roadways significantly depends on the intensity of vehicle traffic (Table 2).

Table 2. The number and sizes of solid particles on the roadways

Road	0.3 (μm)	0.5 (μm)	1 (μm)	5 (μm)	10 (μm)
Lermontova Street	938	144	128	22	18
Lenin Avenue	1 156	455	986	112	29

Most of the particulate dust particles from tires on both streets are 1 μm or less in size. On Lenin Avenue, such particles make up 95% of the sample. The number of solid particles with a size of 0.5 μm on Lenin Avenue is 3 times higher than their number on Lermontov Street. The number of particles with a size of 1 μm is 7–8 times more on Lenin Avenue than on Lermontov Street.

The dirt road had more road dust than the asphalt road. The largest amount of solid emissions was 0.3 μm. Particulate matter 0.3 μm in size accounted for 75% of the Lermontov Street (dirt road) and 42% of the Lenin Avenue (asphalt road) sample (Fig. 2).



(a) (b)

Fig. 2. Distribution of fractions of non-exhaust hazardous emissions on (a) Lenin Avenue; (b) Lermontov Street

Worn tire material is found as small particles suspended in the air. Their harmful effect on human health depends not only on the size of the solid particles, but also on their chemical composition.

According to earlier studies [32-34], aluminosilicates account for about 90% of the operational wear of the road surface. The composition of the tire material contains nitrosamines included in the list of toxicants by the International Organization for Research on Cancer [1]. Various additives are added to car tires to improve performance, one such additive is a zinc oxide vulcanizer. Its concentration in the tread of a tire ranges from 1.2% for cars to 2.1% for trucks [35].

Average concentrations of harmful substances in the air begin to exceed the Maximum Permissible Concentrations (MPC), with a traffic intensity of more than 500 vehicles per hour (Table 3).

Table 3. The content of heavy metals in the air at different traffic intensities (μg / m^3)

Me	MPC (μg / m^3)	Traffic intensity, vehicles per hour ≤ 500	1500–2000	2500–3000
Cu	0.002	0.16±0.11	0.75±0.06	0.92±0.17
Pb	0.0003	0.47±0.03	1.29±0.72	1.84±0.90
Ni	0.001	0.01±0.005	1.02±0.42	1.60±1.03
Cr	0.0015	0.18±0.03	1.10±0.18	1.14±0.32
Co	0.0004	0.24±0.08	1.5±1.02	1.83±1.29
Zn	0.05	0.94±0.11	3.6±2.58	4.65±3.12
Fe	0.04	0.52±0.15	3.8±1.41	4.26±1.73

Chemical analysis has shown that the carcinogenicity of substances from tire and roadway wear is not less than engine exhaust gases [36]. Harmful substances of non-exhaust origin are not highly volatile. However, their movement into the environment is facilitated by the elevated temperatures of tire materials during operation and as a result of wear and the constant renewal of its surface.

More than half of the sweep from the roadway was made up of fine fractions of materials. They have the properties of pulverized material and are capable of becoming airborne. The dust generated by the movement of vehicles is lifted into the air and does not settle for a long time at high traffic intensities. This explains the increased number of solid particles with a size of 1 μm (36%) on Lenin Avenue, which has high traffic intensity.

Decreased traffic intensity led to a dramatic decrease in the amount of the particulate matter (Fig. 2). Road dust near the roadway adsorbs heavy metals. The content of lead in air samples is twice, and zinc triple, the MPC (Table 3).

Airborne road dust is easily carried long distances from the roadway. The third stage of the experiment studied the effect of the distance from the roadway on the content of harmful substances. For example, substances belonging to the first hazard class were taken: Pb, Zn and Cu (Fig. 3).

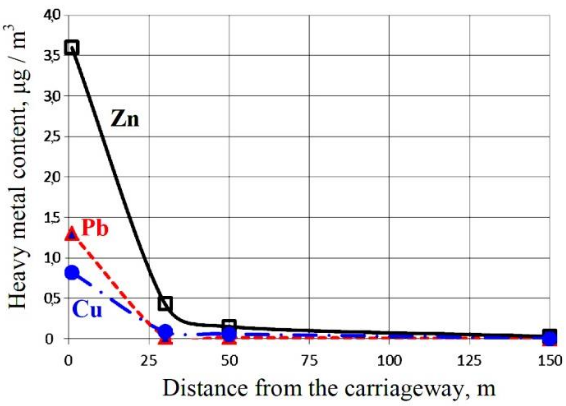


Fig. 3. Dependence of the content of Zn, Pb and Cu in the air at a distance from the roadway (at an intensity of 1800 vehicles per hour)

The results show that the amount of harmful emissions at a distance of 30 meters from the roadway is reduced by five- to sevenfold. This is due to the settling of large fractions of solid particles on the ground.

The number of coarse fractions of solid particles larger than 10 microns does not depend on the traffic intensity (Table 3). Their share does not exceed 1%. The chemical composition of coarse fractions depends only on the material of the roadway.

The chemical analysis of the air samples along the roadways was carried in calm weather for 12–14 hours. In addition to sand, crushed stone, and gravel, various industrial wastes were widely used in the composition of the roadway. The emission of asbestos dust together with binding materials from tar were found, and which are also carcinogenic [37]. Chemical analysis of fractions was carried out on samples of sweep from roadway. The composition of the sweep from the roadway was a mixture of various oxides and their compounds (Table 4).

Table 4. Chemical composition of the sweep from the roadway

Dusty material	Concentration of oxides (%)					
	Fe_2O_3	Al_2O_3	CaO	MgO	H_2O	SiO_2
Asphalt road	76.4	3.1	6.0	2.9	4.3	0.4
Dirt road	70.4	3.4	7.2	4.4	8.1	0.6

Dirt roads generate silica dust. Dust on paved roads includes bitumen products, paint or plastic particles. Large fractions (sweep from roadway) are collected in the summer. The density of harmful emissions of non-exhaust origin on the roadway is 0.6-1.6 t/m3. Pieces of asphalt and other large particles larger than 400 microns were found.

4 Discussion

According to the traffic police, since 2002 there has been an increase in the car fleet in Chelyabinsk. The forecast for the growth in the number of vehicles, per category, is presented in Table 5.

Table 5. Actual and projected number of vehicles in Chelyabinsk

Vehicle category	2002	2014	2020	2030
Car	120,100	271,300	329,600	413,800
Truck	16,200	24,800	28,300	32,400
Bus	1,800	2,800	3,500	4,800

The average annual mileage of passenger cars was 30,000 km. The average annual mileage of trucks and buses was 70,000 km. The actual and predicted indicators of particulate matter emissions from tires, taking into account the increase in the car fleet of the city of Chelyabinsk from 2002 to 2030, are summarized in Table 6.

The wear of the roadway depends on the traffic volume. Regulatory documents set the average annual wear of asphalt roads at 0.38 mm with a traffic intensity of 500 vehicles per day. The mass of a worn-out kilometer of 3.5 m wide road with an average road surface density of 2,100 kg/m3 was 2,793 kg [38]. The density of unpaved roads was 1600 kg/m3. The average annual wear of the road at the same intensity was 1 mm, and the mass of a worn-out kilometer of a dirt road was 5600 kg.

Table 6. Annual emissions of non-exhaust gases in Chelyabinsk (tons)

Vehicle category	2002	2014	2020	2030
Car	5,024	12,678	15,465	19,360
Truck and bus	17,679	30,461	34,619	40,941
Total	22,703	43,139	50,864	60,301

According to STSI, the traffic intensity on Lenin Avenue is almost twice the average traffic intensity. The traffic intensity on Lermontov Street was only 200 cars per day, which is half the average traffic intensity. The total length of roads in Chelyabinsk in 2020 was 1,432 km (992km of asphalted roads and 441 km of dirt roads). Calculations of the average amount of harmful emissions from the wear of the roadway, taking into account the traffic intensity, are presented in Table 7.

Table 7. Depreciation of the roadways of Chelyabinsk, per traffic intensity

Road characteristics	Traffic intensity (vehicles per day)	Mass of wear per km of roadway per year (kg)	Total mass of harmful emissions per year (tons)
Asphalt roads	9,875	55,162	54,665
Dirt roads	200	2,240	987

The total and forecast emissions of particulate matter from roadway abrasion in Chelyabinsk is given in Table 8.

Table 8. Mass of harmful emissions of non-exhaust origin of Chelyabinsk per year (tons)

Year	2002	2014	2020	2030
From road wear	20,641	46,297	55,952	69,379
From tire wear	22,703	43,139	50,864	60,301
Total	43,344	89,436	106,516	129,680

5 Conclusion

The amount of particulate matter from tire and roadway wear is highly dependent on traffic intensity. The size of non-exhaust particulate matter ranged from 0.3 μm to 10 μm. The largest solid emissions were 0.3 μm. They accounted for 75% of matter from asphalt roads with high traffic intensity and 42% for dirt roads with low traffic intensity.

The chemical composition of fine dust from the road surface is determined by the composition of the tires and contains a large amount of carcinogens. The average concentration of heavy metals in the air exceeded the MPC even at a relatively low traffic intensity of 500 vehicles per hour. Harmful substances from tire wear are not highly volatile. Therefore, the concentration of harmful substances decreases five- to sevenfold 30 meters from the roadway.

The amount of coarse fractions of harmful emissions does not depend on the traffic intensity and does not exceed 1.5%. The chemical composition of coarse fractions of non-exhaust origin depends on the quality and composition of the roadway.

The increase in the number of vehicles at Chelyabinsk has a negative impact on the ecological state of the environment. According to STSI, the number of cars in Chelyabinsk will increase by 25% by 2030. This will increase the amount of harmful emissions from tire and roadway wear by 20 tons per year.

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Conflicts of Interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.